

# Establishing User Needs for a Stability Assessment Tool to Guide Wheelchair Prescription

Moody, L, Evans, J, Fielden, S, Heelis, M, Dryer, P, Shapcott, N, Magee, P & Stefanov, D

**Author post-print (accepted) deposited by Coventry University's Repository**

**Original citation & hyperlink:**

Moody, L, Evans, J, Fielden, S, Heelis, M, Dryer, P, Shapcott, N, Magee, P & Stefanov, D 2017, 'Establishing User Needs for a Stability Assessment Tool to Guide Wheelchair Prescription' *Disability and Rehabilitation*, vol 12, no. 1, pp. 47-55

<https://dx.doi.org/10.3109/17483107.2015.1063019>

DOI 10.3109/17483107.2015.1063019

ISSN 0963-8288

ESSN 1464-5165

Publisher: Taylor and Francis

***This is an Accepted Manuscript of an article published by Taylor & Francis in Disability and Rehabilitation on 03 Jul 2015, available***

***online: <http://www.tandfonline.com/10.3109/17483107.2015.1063019>***

Copyright © and Moral Rights are retained by the author(s) and/ or other copyright owners. A copy can be downloaded for personal non-commercial research or study, without prior permission or charge. This item cannot be reproduced or quoted extensively from without first obtaining permission in writing from the copyright holder(s). The content must not be changed in any way or sold commercially in any format or medium without the formal permission of the copyright holders.

This document is the author's post-print version, incorporating any revisions agreed during the peer-review process. Some differences between the published version and this version may remain and you are advised to consult the published version if you wish to cite from it.



## Establishing User Needs for a Stability Assessment Tool to Guide Wheelchair Prescription

Journal:	<i>Disability and Rehabilitation: Assistive Technology</i>
Manuscript ID:	Draft
Manuscript Type:	Original Research
Keywords:	Wheelchair stability, wheelchair prescription, stability testing, user-centred design

SCHOLARONE™  
Manuscripts

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

**Implications for Rehabilitation**

- The results of this survey and interview-based study present a picture of wheelchair stability testing practises in the UK, and highlight the need for new, more informative methods for guiding wheelchair prescription.
- The requirements for the design of a new system, or further development of existing tools to support the stability testing and prescription of wheelchairs have been established.

For Peer Review

## ESTABLISHING USER NEEDS FOR A STABILITY ASSESSMENT TOOL TO GUIDE WHEELCHAIR PRESCRIPTION

### ABSTRACT

**Purpose** The WheelSense project aims to develop a system for assessing the stability and performance of wheelchairs through a user-centred design process. This study sought to capture user needs and define the specification for the system.

**Method** A mixed methods approach was adopted. An online survey was completed by 98 participants working in wheelchair provision. The results were built upon through 10 semi-structured interviews and one focus group (n=5) with professionals working in wheelchair provision in three NHS Trusts in the UK.

**Results** The results provided a picture of the current UK practise in stability testing. Issues with the reliability and usefulness of the existing methods used to assess the stability and performance of wheelchairs were highlighted. Requirements for a new system were ascertained. These included improved accuracy of tipping angles, features to support record keeping, improved patient/carer education support and ability to model or predict user-wheelchair system performance in different configurations.

**Conclusions** The paper concludes that there is a need for improved tools to determine the stability of the user-wheelchair system and support the prescription process, to ensure patient safety and optimum equipment performance. A list of requirements has been produced to guide the future development of WheelSense.

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1 INTRODUCTION

With an increasing number of wheelchair users in the UK [1][2] ensuring the stability, safety and performance of wheelchairs is a growing concern. As a result of the ageing population there is likely to be a continued rise in wheelchair usage, alongside increasing need for specialist seating and condition-specific requirements such as bariatric chairs [3]. In the UK, the National Health Service (NHS) Wheelchair and Seating Service is already struggling to meet the needs of those dependent on wheelchairs as a means of mobility [4].

Wheelchairs that are not appropriately modified to meet user requirements, lifestyle and environments can be prone to tipping, sliding and loss of traction [5]. Incidents can occur on ramps, kerbs, cambers, soft ground, or when modifications have been made to the chair which alter the centre of gravity (such as the addition of medical or assistive equipment) [6].

Poor wheelchair performance can lead to loss of confidence, falls and potentially injury or death [7]. Canadian research indicates 12% of wheelchair users experience a tip per year, often resulting in serious injuries such as concussion or fractures [8]. This would translate to around 144,000 incidents per annum in England.

Wheelchair prescription and assessment in the UK is typically carried out by a health care professional such as a Rehabilitation Engineer (RE) or Occupational Therapist (OT) [9]. The needs, abilities and preference of the wheelchair user (often referred to by healthcare professionals as the client) as well as the demands of the environment should be taken into account when prescribing and modifying a wheelchair [10][11]. The International Standards Organisation has determined markers for prescription and specifically in relation to wheelchair stability [12][13][14]. In the UK, this has been applied traditionally through a ramp test (see figure 1a). The wheelchair and patient are positioned on the ramp in various configurations to see whether the chair tips; upwards facing, downwards facing, and sideways on a fixed incline or variable 12° or 16° ramp (ISO). In order to improve the stability testing available, individual NHS Trusts we are working with have explored the use load cell technology [15] (see **Error! Reference source not found.** 1b). Load cells are widely used in vehicle stability measurement,

and have been adopted by some wheelchair services to measure the weight distribution of the wheelchair and occupant [16]. The data captured is used to calculate the centre of gravity of the user-wheelchair system and guide the adjustment of the chair. Though load cells are being developed in selected services, a commercial wheelchair-specific product has yet to be brought to market.

## INSERT FIGURE 1 ABOUT HERE

The WheelSense project aims to design, develop and evaluate a new system to support wheelchair prescription by measuring and predicting wheelchair stability. A user-centred design approach is being adopted [17][18][19]. This paper outlines the user research carried out at the outset of the project to guide the subsequent design work.

## 2 AIM

The aim of the study was to identify the design requirements for a wheelchair stability assessment system and specifically to explore:

- Current wheelchair stability assessment practises in the UK
- Assess the market for a wheelchair stability assessment system
- Requirements for a new stability assessment system.

## 3 METHOD

A mixed methods exploratory approach was adopted including an online survey of wheelchair prescribers, service managers, wheelchair suppliers and manufacturers; and interviews with wheelchair prescribers.

The study was approved by the Coventry University Ethics committee and access to NHS premises and staff was given by the R&D departments of each participating NHS Trust. All participants gave their informed consent prior to participation.

3.1 Online survey

A 48-item online survey was developed based on a review of the literature. Additional questions were added based on discussions with the project team and project stakeholder group. We were unable to find an existing validated measure or previous research directly related to the aims of the study.

3.1.1 Survey design

The survey comprised of 48 questions including both open and closed questions. Questions covered; demographics, participants' role in wheelchair provision, current methods used to test for stability, limitations to current methods, and desirable features from a new system. The survey was conducted using SurveyMonkey™ which allows the use of question logic. The design of the survey guided participants to questions relevant to their professional role. The survey was piloted by a small group of wheelchair prescribers to check readability and whether any key issues were missing. Wording of some questions was revised as a result.

3.1.2 Participants and procedure

An invitation to complete the survey was emailed to approximately 500 people working in wheelchair provision. Invitations were sent via email distribution lists provided by partner NHS Trusts, as well as opportunity sampling at the UK Posture and Mobility Group (PMG) National Training Event. From the sample of 500 who received the invitation, 98 responses were received giving a response rate of approximately 19%.

The survey participants were grouped into five categories during analysis; *therapeutic and medical* which included occupational therapists, physiotherapists and any other therapeutic professions (n=27); *engineering and technology* which included rehabilitation engineers, design engineers, communication technicians, and other technical professions (n=49); *managerial* (n=3);

1  
2  
3 *company representatives* (n=14) and *other* - those who did not divulge their profession or did not  
4 fit into any other category (n=5). Table 1 shows the proportionate representation from each  
5 professional group, which indicates that the majority of respondents were in an engineering  
6  
7  
8  
9 (49%) or therapeutic (28%) role.

10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

INSERT TABLE 1 ABOUT HERE

Having read the participant information sheet and indicating their consent at the front of the survey, the participants were provided with the survey questions. The survey took approximately 20-30 minutes to complete.

## 3.2 Interviews and focus group with prescribers

The interviews were undertaken after the survey and allowed exploration of some of the key emerging themes.

### 3.2.1 Participants

A list of wheelchair prescribers, seating specialist and occupational therapists with wheelchair prescription experience and their managers were identified by the members of project team. A key factor for inclusion was availability for interview given recruitment focused on busy clinical staff, and therefore there was an element of opportunity involved. All participants invited to interview agreed. Recruitment continued until data saturation was reached- this was the point at which participants gave no new data.

Ten semi-structured interviews and one focus group (n=5) were conducted. The participants occupied various roles across the three partner sites of the WheelSense project (Birmingham Community Healthcare Trust (n=8), Kings College Hospitals Foundation NHS Trust (n=5), and Betsi Cadwaladr University Health Board (n=2)).

INSERT TABLE 2 ABOUT HERE



1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

**3.2.2 Procedure**

The semi-structured interview schedule (which was also used in the focus group) was developed through consultation with the project steering group. It asked a number of demographic questions and then explored; current and historical methods of stability testing; thoughts on stability and how it is assessed; clinical and practical constraints on assessments; interest in, and requirements from, a new stability assessment tool. The interviews lasted on average 30 minutes (range 20-40 minutes).

The interviews were undertaken by two researchers from Coventry University (first and second author) experienced in capturing requirements for system development. They were unfamiliar to the participants. Interviews and the focus group were either undertaken face to face at the NHS Trusts, or on the telephone to suit the requirements of the participants.

**3.3 Analysis**

The online survey responses were tabulated and summarised graphically using PASW for Windows. More advanced statistical analysis was not appropriate given the sample size and explorative nature of the survey. The open questions were analysed using thematic analysis [20]. The interviews (and focus group) were recorded, transcribed verbatim and analysed independently by two researchers using thematic analysis [20].

**4 RESULTS**

The findings have been analysed and combined to consider the current UK practise in terms of stability testing, and requirements for a new stability assessment system.

**4.1 Current Practise in stability testing**

Eighty-five respondents reported their length of service within wheelchair provision (the remaining 13 skipped this question). Length of service varied between one year and over ten years, with the majority of respondents (56.5%) having more than ten years of service.

Participants were asked to estimate the average number of wheelchairs given a stability test within their service each month. The responses ranged between 0 and 50, with a mean of 8.80 (n=36; SD= 11.53). When asked how often patients report issues with wheelchair stability estimates were in the range of 0 to 6 reported issues per month, with a mean of 1.70 (n=27; SD= 1.35). The interviews explored the issue of adverse incidents experienced by patients. It was felt that wheelchair related incidents were often linked to patient behaviour or misuse of the chair, and that incidents are part of life for wheelchair users and do not necessarily get reported.

*"Usually you can just try and talk to them about, "Have you ever tipped over in this chair or ever done anything?" And they'll say, "Oh, yeah, I was reaching off the floor one time." And it's just to get them to link stability, which is you know, it's an engineering term - you've got a stability risk. To a patient that doesn't mean a great deal, it could mean tipping over, it could mean skidding, but they've all experienced it at some point, usually getting on and off a bus or something." (PE, BIRM002)*

When asked to estimate how often wheelchairs are revisited and adjusted in response to performance, participants gave responses in the range of 0 and 25 revisits/adjustments per month, with a mean estimate of 2.96 (n=20; SD=5.65).

The survey sought to determine the types of patients for which stability tests are commonly used. Table 3 indicates the percentage of respondents that indicated use of stability testing for each patient group.

INSERT TABLE 3 ABOUT HERE

It can be seen that most participants reported stability testing for patients requiring special seating, followed by amputees and those requiring variable seating.

During the interviews, participants indicated that they formally stability tested on average every four to six weeks. The interviews revealed that patients who want, or need a very stable chair will get a formal stability test, as would patients who have equipment added such as communication aids or specialist seating, which can affect the chair's centre of gravity and/or

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

manoeuvrability. Some patients were considered unsuitable for stability testing. One of the most commonly cited reasons for not conducting a stability test was for patients who are active users – those who wish their chair to be inherently ‘unstable’ to allow them to self-propel through a variety of environments, for whom a pass/fail stability rating would not be useful since it would be expected that their chair would fail.

All interview participants recognised that wheelchair users differ in their habits, lifestyles, and the environments in which the chair would be used, and wheelchair provision should take this into account. It was considered important to ensure that passive users (those who cannot self-propel and need assistance, or who wish their chair to be very stable) would not tip and that wheelchairs should be as safe as possible whilst taking into account their likely use. Other reasons cited for not always performing formal stability tests included a lack of consistent access to equipment, difficulties transporting and/or setting up ramps (particularly in patients’ homes), manual handling issues and apprehensive patients.

*“Sometimes we’re forced to [use the ramp offsite]. I do everything in my power to avoid it because the ramp is too heavy to carry and, knowing your luck, chances are you’ve got to go up two flights of stairs and then open it up on someone’s shiny floored living room that has absolutely no space to it whatsoever.” (RE, KCH005)*

**4.2 The perceived importance of stability testing**

The importance of considering wheelchair performance and not just stability was emphasised by the interview participants. Too much stability can lead to difficulties pushing the chair and manoeuvring through the environment:

*“Manual chairs can be too stable sometimes and then you can’t actually tip them back to get up kerbs by somebody pushing. ... if they can’t get over door thresholds and get up little slopes then they’ll begin to feel trapped again or frustrated.” (CT, BIRM007)*

It appeared that the term ‘stability testing’ is considered to relate to finding the angle at which chairs become unsafe or likely to tip; information about the centre of gravity that guides

the modification of the chair to patient needs is also important, but not currently captured by ramp tests and only captured in a limited fashion by load cell tests.

### 4.3 Wheelchair prescription

Participants were asked to rate the importance of a number of factors in wheelchair prescription between 1 for unimportant to 10 of high importance. The responses are shown in table 4. Tuning a wheelchair to a specific user was rated most highly. Assessing wheelchair performance and stability were rated to be of high importance also, however determining the wheelchair's centre of gravity was rated to be of lowest importance from the given factors.

INSERT TABLE 4 ABOUT HERE

In the interviews, participants were asked "What factors do you take into account when tuning wheelchairs at prescription or to respond to client reported issues?". There were a number of factors reported; the most common of which was the environment in which the chair was to be used. The wheelchair patient's ability to control the chair, physical attributes of the chair, weight distribution, centre of gravity of the chair and the carer's needs also appeared frequently as considerations.

The survey also asked participants "Apart from client dimensions, which dimensions of wheelchair geometry do you typically take into account when assessing and prescribing a wheelchair?". The overall chair width/wheelbase was the most frequently cited factor considered, with seat-to-ground height, chair length, wheel/caster position and size, backrest height and backrest angle also taken into account.

### 4.4 Current methods of stability assessment

The survey sought to determine the methods of stability assessment currently used by respondents. **Error! Reference source not found.** 5 shows the percentage of each professional

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

group using the suggesting means of assessing the stability of the wheelchair-user system. Respondents were allowed to choose all applicable options therefore percentages are exclusive and not additive. Stability testing is frequently used by a high percentage of engineering and technology-based roles (83%), alongside clinical judgement (60%). Therapeutic and medical roles were less likely to make use of stability testing (41%) alongside their clinical judgement (59%). Only 2.1% of engineering staff indicated that they did not use any method for stability assessment. The findings also highlight the importance of user / carer acceptance in the assessment of the wheelchair performance.

INSERT TABLE 5 ABOUT HERE

The survey went on to look at the stability tests used in more detail. Participants were asked to report which stability tests they used within their current practise (multiple choices allowed). The responses (table 5) indicated that the most common stability assessment methods used were fixed and variable ramp systems. ISO dynamic testing was not frequently used. Interviews revealed this is due to the availability of facilities to enable this. Overall, 10 participants reported using no test at all for stability. The majority of interview participants reported that they had access to some sort of ramp system (some wooden, some metal, some variable and some fixed).

INSERT TABLE 6 ABOUT HERE

Survey participants were asked to indicate the time taken to complete the tests they used. The results are summarised in table 6. This was ascertained to gain the current accepted time for testing.

**4.5 Limitations to current stability testing methods**

A large proportion of respondents (78.9%) reported that there were limitations to the stability assessment method that they currently used to test stability. Table 7 shows how well the ramp and load cell system were rated by the survey participants from 1= poor, 10 = excellent.

INSERT TABLE 7 ABOUT HERE

#### 4.5.1 Limitations of ramp tests

The interview feedback on the ramp systems varied. The ramps were recognised as being widely used, simple and cost effective but having some significant limitations. The strongest recurring theme was that ramp tests only indicate static stability testing. The current testing methods are not sophisticated enough to mimic the real-world use of moving wheelchairs, and therefore this does not get incorporated into the prescription or adjustments made to wheelchairs.

*‘The tests are performed indoors on a simple ramp, a scenario not necessarily reflective of the outdoor environment where slopes are often multi-planar.’ (RE R012)*

The ease of moving the testing systems around was noted. Some reported having sustained injury or causing damage to patients’ homes using the ramp test. Others felt it was impractical to take the ramp on visits to patients’ homes due to its size and weight, but noted that in some NHS Trusts home visits are more frequent than in-clinic tests, which presents a problem with the lack of portability of the system.

Interviewed prescribers reported manual handling issues with positioning wheelchairs on the ramp and conducting stability tests. It was indicated that stability tests would typically be undertaken by two people to reduce the injury risk and/or reduce the test time.

*‘We usually do that as a pair with the clinician as well because there was an instance in the past where I was left on my own and I hurt my back which wasn’t good.’ (ACT engineer, BIRM001)*

The survey results indicated issues with the information provided by the ramps. Overall, 27 respondents reported using a variable ramp system to measure stability. The ramps give pass/fail information within specific conditions. Many felt that they did not provide information about whether a chair would tip in use and out in the environment.

*‘It gives absolute pass/fail at 2 different angles of incline but does not measure the incline at which the chair becomes unstable. It is done in a static situation whereas most problems with stability will occur in a dynamic situation. The preferred degree of*

*stability for each user depends on the user, his/her carers and the environments in which this system will be used.’ (Seating Engineer SE015)*

Interview participants were similarly concerned about the limited information and translating the output of the test into a meaningful measure of stability. Further interpretation is based on clinical judgement as well as the ability to extrapolate test results to real-world scenarios. Some of the prescribers that were interviewed expressed concern that on the steeper inclines, patients would lean or brace themselves, or need to be supported by the prescriber themselves, which undermined the accuracy of the test.

Concern was expressed for the patients during the ramp test. Survey feedback indicated that the ramp tests can cause distress as the wheelchair and occupant are positioned at an angle on a ramp.

*‘The process of performing a tilt [ramp] test can be unnerving for the patient and carers, and may reduce confidence in its use.’ (RE RE012)*

The limited real-world information that can be given to the patient during the test also caused concern:

*“When the patient leaves the assessment they can load the chair with bags etc against the advice of the clinician. But they have the right to independence and having extra bags may be part of their requirement.” (RE RE022)*

Interview participants agreed. It was reported that the incline at 16 degrees in particular was distressing for patients, although with support and reassurance the patients would generally remain calm and complete the test. It was highlighted by 6 interview participants that the ramp test is useful in illustrating to the patient what a particular angle of incline feels like, and the limits of the chair which can be more effective than a verbal explanation:

*“That was the advantage of the old [ramp] system. In that people knew what it felt like to be that far and maybe if they remembered that they could think I don’t really want to be this far tilted.” (CT, BIRM007)*

This view was challenged by others who argued it misled patients to believe their chair is stable at a certain angle, but they may then be unprepared for change of stability for example when the chair is moving in wet weather.

Finally, some interview participants felt that the ramp may be out of keeping with the look and feel of modern healthcare equipment, and this may cause patients to be hesitant to take part in the test. It was felt by some that the ramps look unprofessional and do not inspire confidence.

#### 4.5.2 Limitations of load cell systems

The WheelSense system will be based on load cell technology so it was important to review existing load cell systems. Overall, 16 survey respondents reported using load cell system to measure stability and 14 answered the test specifics question. Problems with the load cell based stability testing identified through the survey included the inability to test 6 wheeled chairs, the time taken to set up and conduct the test, impracticality of transporting the rig, and the need for specific knowledge relating to the data in order to make a judgement based on the results.

The interview participants varied in terms of whether they viewed the advanced technology as positive or negative. Some rehabilitation engineers felt that having access to advanced technology was beneficial and would allow them to determine more information about the chairs and their centre of gravity. Others felt that the system risked becoming overcomplicated and may be unnecessarily expensive or complex.

*“From what I know it’s very complex... it appears very complex. I think without specific training I wouldn’t have a clue where to start with that.” (OT, BIRM006)*

Likewise some therapeutic staff highlighted in their survey responses that the technology available to them was too technical and not something that they had the expertise or knowledge to use confidently.

*‘I can only assess clinically - I don’t have technical/mechanical knowledge.’*

*Physiotherapist survey respondent PHY005)*

*‘It is lengthy and complex to learn’ (OT OT005)*



1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

Some prescribers surveyed expressed concern that the load cell systems do not provide a demonstration of more extreme angles of tilt, in the way that ramp tests can. It was felt that whilst there was a benefit to the patients not having to endure extremes of tilt, there was a compromise to be had in demonstrating these angles physically, which would be lost using the load cell system alone.

*‘One significant advantage of the fixed test is that it is easy to directly compare chairs, or before/after results and it gives a visual indication of chair stability to clients and family/care staff which would not be possible with a load cell system.’ (RE RE014)*

Some prescribers interviewed expressed similar concern that the load cell system would not provide a demonstration of angles of tilt to the patient.

Generally, participants were agreed that however complex or simple the system is, communication to the patients and carers should be kept simple. One participant also noted that the load cell system could be designed to look less intimidating to patients and less technical in its appearance.

**4.6 Requirements of a new system**

The survey sought to determine requirements for the new WheelSense system. The participants were asked to rate the desirability of 17 potential functions derived from the literature and project team discussions on a scale from one (not at all desirable) to five (extremely desirable) (see table 8). Many features were rated as highly desirable, the most desirable of which was the ability to keep records of stability assessment for clinical use. Determining the point at which a wheelchair will lose stability both in a static and dynamic capacity was also highly desirable.

INSERT TABLE 8 ABOUT HERE

The least desirable features included a fully manual system which gives no hints or interpretation of results, and taking and storing 3D imagery to capture wheelchair geometry. Interview participants were also asked about their priorities when it came to functionality.

#### 4.6.1 Portability

Portability was considered important. Developing a system out of lightweight materials and ensuring the system can be moved to and set up in patients' homes was important. Interview participants noted that due to budgetary constraints, many Trusts share equipment with other local Trusts and therefore portability would be essential in these cases to make the equipment accessible.

#### 4.6.2 Reporting and record keeping.

Interview participants were keen that the system software support record keeping. The survey indicated that this was potentially an attractive feature. Interview participants felt that being able to print a 'stability certificate' would be beneficial, which could be passed on to the patients and carers. Others felt that something to put into patients' files; and refer back to and record changes would save time and improve outcomes.

*"Yeah, to have an accurate record of what's going on there, that we can say, well hang on, this is what we had before, this is what you want to do now, and this is where you are now, and these are the differences." (RE, BIRM003)*

#### 4.6.3 Patient and carer education

It was felt that patients and carers often lack the capacity or specialist knowledge to understand complex information about stability but clear guidance is needed regarding the limitations and functionality of a chair following assessment. Guidance should be tailored to real world behaviour and encourage safe use of the chair:

*"I suppose if there was a programme whereby you load it up with so many kilos of shopping on the back and see what the outcome of that might be. ... So if that could be*

*done in a safe sort of controlled manner that would be quite a good learning tool.” (OT, BIRM006)*

**4.6.4 Stability and risk assessment**

The majority of interview participants indicated that stability should be considered in a wider context to meet patient needs. Many used the term ‘risk assessment’ interchangeably with stability assessment, and discussed the technical testing as just one part of a wider process. The patient’s environment was also key factor for consideration in the interviewed prescribers’ risk assessment process.

*“....., you're then doing a risk assessment of where that chair's going to be used and what we want to do with it.....I mean that stability test is just confirming how far you can go or the difficulties that that individual is going to have when driving that chair. That’s when your risk assessment becomes very important as well.” (RE, BIRM003)*

**4.6.5 Modelling real world behaviours**

One of the key issues that interview participants raised was the difficulty of resolving the needs of both active and passive wheelchair users<sup>1</sup>. Several prescribers acknowledged that for an active user, they would not complete a stability assessment at all since the user would naturally want a chair to be ‘tippy’. To some extent, the same was true of chairs which were difficult to stabilise due to extra equipment. Participants spoke about finding a balance between making the chair stable and recognising what how the user might behave. Examples given were patients placing bags on the chairs, going up steep ramps, adding accessories to the chairs and even in one case attempting to go down a flight of stairs. It was therefore recognised that a system would need to not only look at stability but the optimum calibration of the chair for that individual user and their lifestyle. It was felt that current tests do little to resolve the issue of dynamic stability in

<sup>1</sup> The terms ‘active’ and ‘passive’ wheelchair users refer to the level of self-propelled activity a patient undertakes in their chair. Active users will tend to self-propel for the majority of their time, and generally wish to be able to negotiate environmental obstacles such as kerbs without assistance. Passive users depend more or totally on assistance, or wish their chair to be very stable.

the real world, and that new innovations in stability testing ought to aim to incorporate dynamic stability:

*"I'd like to see it moving more towards a more dynamic one which is more like the real world, you know? Ramps, slippage, sometimes the brakes aren't always in the best condition and things like that." (ACT engineer, BIRM001)*

#### 4.6.6 Ease of use

The interviews and survey results indicated that the need for usability. Load cell systems are complex and need simple and intuitive interfaces so the output can be readily used. Most interview participants felt the rehabilitation engineers were best placed to carry out technical testing of wheelchair stability and performance due to their understanding of physics and the technology. Occupational therapists were reported to have less involvement in the assessment process during the interviews; with a practise of therapists assessing patient need and then referring to an Engineer when fine tuning or chair alterations were needed.

#### 4.6.7 The market

Survey respondents were also asked to assess the value of a stability assessment system with features that they had listed as desirable (see table 9). They were given options; less than £2000, £2000-4000, £4000-6000, £6000-8000 or 'don't know'. 47% estimated that the system would be worth between £2000 and £4000. 39% estimated they would pay £2000-4000. This potentially provides a target for the purchase price of the system.

Interview participants were very mindful of the costs of a technical system. They suggested that a new system should offer added value to existing systems in order to encourage buy-in, given such a significant cost.

*"I think it depends on what value it would add above and beyond our current system. I think there is a market for a commercial system nationally and there are things, particularly with the six wheels and things like that, that we can't do. And if it was a lot easier to interpret the results then yes there would be a benefit." (RE, BIRM005)*

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

A further question regarding willingness/desire to be part of stability testing was targeted specifically at the manufacturers and suppliers. This question aimed to assess whether this group would potentially use the system to develop new wheelchair models, or before sending the chairs to the NHS. Of 11 respondents, 72.7% ( $n=8$ ) answered yes to being interested in the capacity to measure the stability and related performance of a wheelchair during design and development.

The survey participants were asked to consider what would most influence a purchasing decision or recommendation to a budget-holder. Participants were asked to rate options from a pre-determined list of factors on a scale from one (no influence) to ten (highly influential). The most highly rated factors which would influence a purchasing decision were; ease of portability, ease of use, cost, training and support, and first-hand experience of using the equipment. Each of these factors had a median rating of 9, a mode of 10 and an interquartile range of 2 or 3.

**4.7 Summary list of requirements**

The findings detailed above have been used to form a list of requirements (table 9) for the development of a load cell based wheelchair stability assessment system. This is not an exhaustive list but gives guidance for future development.

INSERT TABLE 9 ABOUT HERE

## 5 DISCUSSION

The survey and interviews ought to gain a broad picture of UK-based stability assessment and testing by ascertaining the views and experiences of professionals associated with wheelchair provision. The findings highlight that although there was a wide range of patient types seen by wheelchair services, not all wheelchair users in the UK will have a wheelchair stability assessment prior to release of their wheelchair. Certain groups are more likely to be tested, for example patients who require special seating, amputees, and bariatric patients. It is argued through, that all wheelchair users would benefit from their wheelchair being tuned to their individual needs and capabilities, and predictive information that may guide the prescriber and patient to understand how the wheelchair might behave in a dynamic real-world scenario.

The review of existing stability testing methods (load cell systems, variable and fixed ramps) has highlighted some of limitations which impact both the patient and the clinician during the assessment. Current methods are seen to lack portability, and precise measurement. Ramp tests were frequently associated with manual handling issues and were seen as distressing for the patient, who must be physically tipped in order to yield a test result. They fail to predict real world behaviour of the user-wheelchair system.

Development in load cells systems are seen to offer potential, but are considered as intimidating and are underutilized by staff with a therapeutic background. The systems were considered to be unnecessarily complex, despite giving more accurate tipping angle results. There is a need to improve the user experience, and ensuring that the chair's capabilities can be demonstrated in a way which makes sense to the patient. The limitations of the existing testing methods highlight the need for further development of systems to ensure that dynamic as well as static stability can be predicted.

The survey results demonstrate that only in the more complex cases is stability testing seen as a routine process. It is possible that the limitations of the current available systems prevent stability testing from becoming a routine part of assessment, and were a new system to reduce

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

some of these limitations and facilitate easier stability testing, more emphasis on stability assessment may be supported.

Wheelchair prescription is complex and multi-factorial. It is reliant on the knowledge, experience and expertise of the prescriber. It has been shown that there is a need for improved tools to support the process, which may in turn support an increase in the number of patients being stability assessed. There were a number of desired features of a potential new system identified, perhaps again highlighting the limitations of the current methods available. The priority areas were providing a record of the stability assessment process, an improved capacity for patient/carer education, determining more accurate tipping angle results including the maximum angle at which the chair is stable, and modelling the behaviour of the chair in different configurations. These features have been used to scope out the requirements of a new system that is currently being developed.

There are some limitations to the study. Though the survey invitation was sent to approximately 500 potential participants, only 98 responded. Several professions were represented within the final sample, but it is not clear whether the results are applicable to the general population. Some of the questions relied on participants estimates, such as the number of stability tests conducted and average numbers of wheelchairs supplied by services each month. Equally the interview study only represented 3 NHS Trusts.

However as an exploratory study, the results are useful in defining the specification for WheelSense and the potential market for the device. Ongoing user involvement and consultation is guiding the system development and evaluation. This paper has demonstrated that there is a need for improved tools to determine the stability of the user-wheelchair system. A system that allows for a more detailed understanding of stability, both static and dynamic and allows prediction of the wheelchair safety and performance would be of benefit to both wheelchair users and wheelchair services, and may increase stability testing rates for a boarded range of patients.

## 6 ACKNOWLEDGEMENTS

The WheelSense project is funded by the National Institute for Health Research (NIHR) Invention for Innovation (i4i) stream (Grant II-AR-0209-10099.). Ethical approval to conduct this study was granted by Coventry University.

## 7 DECLARATION OF INTEREST

Louise Moody and Jill Evans report no declarations of interest. Dimitar Stefanov, Paul Dryer, Simon Fielden, Nigel Shapcott, Mike Heelis and Paul Magee have submitted a patent based on the WheelSense system (Mobility Assistance Vehicle Stability Assessment: Submission No 1312258.5/ 14 July 2014).

## 8 REFERENCES

- [1] Sapey B, Stewart J, Donaldson G, Increases in wheelchair use and perceptions of disablement Disability & Society, 1995; 20:5, 489-505.
- [2] NHS MA, Improving Services for Wheelchair Users and Carers. Good Practice Guide, 2004
- [3] Sapey B, Stewart J, Donaldson G The social implications of increases in wheelchair use. Report. Department of Applied Social Science Lancaster University, 2004. <http://www.lancs.ac.uk/fss/apsocsci/wheelchair/the%20social%20implications%20of%20increases%20in%20wheelchair%20use.pdf>.
- [4] NHS Scotland, Review of NHS Wheelchair and Seating Services in Scotland. Moving Forward, 2006
- [5] Cooper RA, Wheelchair selection and configuration, 1998, New York. Demos Medical Publishing, Inc.
- [6] Rice, LA. Cherita Ousley, C. Sosnoff, JJ. A systematic review of risk factors associated with accidental falls, outcome measures and interventions to manage fall risk in non-ambulatory adults Disability and Rehabilitation 2014; 0:0, 1-9 doi:10.3109/09638288.2014.976718)



[7] Dudley NJ, Cotter D, Mulley GP, Wheelchair-related accidents. *Clinical rehabilitation* 1992; 6:3; 189-194.

[8] Kirby RL, Ackroyd-Stolarz SA, Brown MG, Kirkland SA, MacLeod DA, Wheelchair-related accidents caused by tips and falls among noninstitutionalized users of manually propelled wheelchairs in Nova Scotia, *American Journal of Physical Medicine and Rehabilitation*, 1994; 73(5): 319-30

[9] Smith C, McCreadie M, Unsworth J, Prescribing wheelchairs: the opinions of wheelchair users and their carers. *Clinical Rehabilitation*, 1995; 9: 74-80

[10] Di Marco A, Russell M, Masters M, Standards for wheelchair prescription. *Australian Occupational Therapy*, 2003; 50:1; 30-39

[11] Batavia M, Batavia, AI, Friedman R, Changing chairs: Anticipating problems in prescribing wheelchairs. *Disability and Rehabilitation*, 2001; 23, 539-548

[12] International Standards Organization 1999, Wheelchairs— Part 1: Determination of static stability. ISO 7176-1: 1999(E).

[13] International Standards Organization 1999, Wheelchairs— Part 2: Determination of dynamic stability. ISO 7176-2: 1999(E).

[14] BSI (2001). Guidelines for the application of the ISO 7176 series on wheelchairs. PD ISO/TR 13570.

[15] Wheelchair Stability Platform Available from:  
[http://www.rmpd.org.uk/innovation/transferred\\_to\\_industry/wheelchair\\_stability\\_platform.htm](http://www.rmpd.org.uk/innovation/transferred_to_industry/wheelchair_stability_platform.htm)  
(cited 10th Dec2014)

[16] Wawrzinek A, Boenick U (1987). Dynamische stabilität von rollstühlen. *Biomed Technik* 1987, 3 (2) 313-343.

[17] Abras, C.; Maloney-Krichmar, D.; Preece, J. User-Centered Design. In: Bainbridge, W., editor. *Encyclopedia of Human-Computer Interaction*. Sage; Thousand Oaks: 2004.

[18] Johnston, P., Currie,LM. Drynan, D. Stainton, T. Jongbloed, L.. "Getting it "right": how collaborative relationships between people with disabilities and professionals can lead to the

acquisition of needed assistive technology." Disability and Rehabilitation: Assistive Technology  
2014; 1-11.

[19] Williamson, T., Kenney, L., Barker, A. T., Cooper, G., Good, T., Healey, J. & Smith, C.  
Enhancing public involvement in assistive technology design research. Disability and  
Rehabilitation: Assistive Technology, 2014; 0 (0), 1-8.

[20] Braun V, Clarke V, Using thematic analysis in psychology. *Qualitative Research in  
Psychology*, 2006; 3:77–101.

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

**List of figures and tables**

- Figure 1 Ramp (a) and load cell system (B)
- Table 1 Job roles of survey participants
- Table 2 Job roles of interview/focus group participants
- Table 3 The percentage of participants that use stability testing for specific patient groups
- Table 4 Rated importance of factors in a typical wheelchair prescription/supply process: (1 = low importance, 10 = high importance)
- Table 5 Methods of stability assessment and test by job role.
- Table 6 A summary of the estimated stability test completion times
- Table 7 Ratings of the ramp and load cell systems against a number of performance indicators
- Table 8 The desirability of functions of a new system
- Table 9 System requirements

**Table 1 Job roles of survey participants**

<b>Role Type</b>	<b>Total <i>n</i></b>	<b>%</b>
Therapeutic and medical	27	28
Engineering and technology	49	50
Managerial	3	3
Company representatives	14	14
Not disclosed/other	5	5
<b>Total</b>	<b>98</b>	<b>100</b>

**Table 2 Job roles of interview/focus group participants**

<b>Job Role</b>	<b>Number</b>
Occupational Therapist (OT)	2
Clinical technologist (CT)	1
Rehabilitation engineer (RE)	7
Rehabilitation engineer trainee (RET)	1
Access to Communication & Technology Clinical Scientist (ACT)	1
Project engineer (PE)	1
Clinical scientist (CS)	1
Senior clinical engineer (SCE)	1

Table 3 The percentage of participants that use stability testing for specific patient groups

Patient type	%
Requiring special seating	90
Children	37
Adults	37
Bariatric patients	40
Amputees	54
Requiring pressure relieving cushions	23
Requiring manual wheelchair	32
Requiring powered wheelchair	28
Requiring seats that have variable positioning	54
Requiring special controls	26

**Table 4 Rated importance of factors in a typical wheelchair prescription/supply process: (1 = low importance, 10 = high importance)**

	<b>Mode (n=71)</b>	<b>Median (n=71)</b>
Determining the position of the centre of gravity	8	7
Determining the static stability	7	7
Determining the dynamic stability	8	7
Tuning a wheelchair to a specific user (e.g. wheel positions, position of seat on the chassis etc)	10	9
Assessing wheelchair performance (e.g. slipping, lack of traction etc)	8	8
Assessing wheelchair stability	8	8

Table 5 Methods of stability assessment and test by job role.

	Role Type (%)			
	Therapeutic and medical	Engineering and technology	Managerial	Company representatives
<b>Stability assessment methods</b>				
No method	0.0	2.1	0.0	0.0
User/carer acceptance or decision (active user)	37.0	39.6	0.0	7.1
Use of manufacturer literature	25.9	31.3	0.0	21.4
Clinical judgement	59.3	60.4	33.3	21.4
Stability test	40.7	83.3	66.7	21.4
Other	3.7	12.6	0.0	0.0
<b>Stability testing methods</b>				
ISO 7176 static test method	3.7	18.8	33.3	21.4
ISO 7176 dynamic test method	3.7	6.3	0.0	21.4
Fixed ramp	<b>33.3</b>	<b>37.5</b>	<b>33.3</b>	7.1
Variable ramp system	22.2	<b>41.7</b>	0.0	7.1
Load cell system	7.4	22.9	<b>66.7</b>	7.1
No test	22.2	6.3	0.0	7.1
Other	7.4	20.8	0.0	7.1

**Table 6 A summary of the estimated stability test completion times**

Stability test	Estimated completion time (minutes)			
	Number of responses	Mean	SD	Range
Fixed ramp	13	10.9	9.8	5-40
Variable ramp	26	13.81	10.2	4-45
Load cells	11	21.3	13.0	3-45



1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

**Table 7 Ratings of the ramp and load cell systems against a number of performance indicators**

	Response (1-10)					
	Variable Ramp tests			Load cell		
	Mode	Median	Inter-quartile range	Mode	Median	Inter-quartile range
Safety of tester	8	7.5	3.25	10	9	2
Safety of the occupant	9	8	2.25	10	10	1
Dynamic stability	1	1	2	1	3	4
Static stability	10	9	2	9	9	2
Tuning of wheelchair performance	5	5	4	6	6	4.75
Testing of wheelchair tuning	5	5	4.5	1	4	8
Recording of the results and associated data	5	7	4	10	10	3
Illustration to the patient of the chair's capabilities	5	6	4	1	3	6

**Table 8 The desirability of functions of a new system**

Function	Median	Mode	Interquartile range
Providing a record of the stability assessment process for clinical records (e.g. for clinical record keeping, risk/benefit evidence etc)	5	5	1
Capacity to educate the client/carer (e.g. reassurance on the wheelchairs' fitness for purpose)	5	5	1
Determining the maximum slope on which the wheelchair is still safe when in motion	5	5	1
Providing an indication of the angles at which the chair will tip, or slide, in each direction	5	5	1
Determining the maximum slope on which the wheelchair is still safe when static	5	5	2
Being able to model/predict the effects of the wheelchairs' different configurations on stability (e.g. position of wheels, position of seat relative to chassis)	5	5	1

Table 9 System requirements

<b>Functionality of the system:</b>	
<ul style="list-style-type: none"><li>Enhanced accuracy of stability measurement.</li><li>Determine the maximum inclines at which the chair can be considered as stable (and at which point it will tip), preferably both in a static and dynamic test, and in each direction.</li><li>Ability to model or predict the effects of various configurations of the chair on its stability.</li><li>Ability to use in patients' home environments or environment where chair is most often used.</li><li>Be portable and lightweight to allow sharing between services in order to reduce cost barriers.</li><li>Be simple to use but with the option of more complex features and functions to cater for novice and expert users</li><li>Be easy to set up and reduce preparation times compared to existing load cell solutions in order to allow timely assessments.</li><li>Look attractive to avoid patient apprehension</li><li>Facilitate demonstration of the stability limits of the chair and the physical angle of tilt.</li></ul>	
<b>Outcomes and outputs:</b>	
<ul style="list-style-type: none"><li>Enhanced optimisation of chair stability for individual needs.</li><li>Record the assessment process and outcomes for clinical use.</li><li>Hints and guidance on interpreting the measurements whilst retaining clinical judgement and ability to adapt for different patients.</li><li>Enhanced posture and comfort for the patient.</li><li>Reduced manual handling for the prescriber compared to the existing ramps.</li><li>Have the capability to show patients some visual representation of their chair capabilities</li><li>Support education of the patients and carers in order to reduce misuse of chairs or user error.</li></ul>	
<b>Purchasing and training:</b>	
<ul style="list-style-type: none"><li>Training and support in how to use the tool and maximise value – particularly for professionals who may be put off by the technicality of such a product.</li></ul>	

- Low cost – less than £4k for unit and training.
- The system should move away from traditional views on ‘stability’ and testing to encourage more consistent and frequent use to maximise chair performance and safety.

For Peer Review



Figure 1 a. Ramp testing system

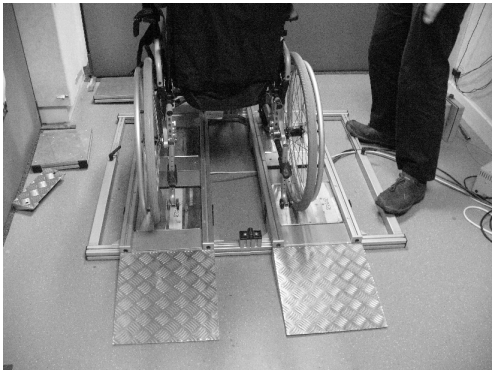


Figure 1 b. A load cell system

Figure 1 Ramp (a) and load cell system (B)